Improvement of Power Quality using Dual Control Strategy of Unified Power Quality Conditioner (UPQC)

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***Abstract*—This paper presents an ideal and effective control strategy to compensate harmonics and the load-reactive power demand by connecting a three-phase unified power quality conditioner (UPQC). In order to reduce the power quality problems this paper presents, the flexible control technique for UPQC as dual control in power distribution system. The polluted loads at the end user side are always creates the power quality problems. In this paper, UPQC system is used for series and parallel power conditioning and they act as sinusoidal current and voltage source inverters respectively. The series and shunt active power filter (APF) injects voltage and current at significant phase angle which converts non-sinusoidal electrical quantities into sinusoidal electrical quantities. This is also called as dual compensation. The proposed UPQC system can connect to both three-phase three-wire and three-phase four-wire distribution systems. The UPQC system can enhance the power quality in distribution system at the point of common coupling (PCC) under non-ideal mains voltage and unbalanced load conditions. The simulation results based on MATLAB/Simulink are analyzed and studied.**

***Index Terms*— Active power filter, non-linear load, power quality, power system harmonics, reactive power compensation, three-phase distribution system, total harmonic distortion, unbalanced load, UPQC.**

I. INTRODUCTION

The power quality (PQ) can be defined as maintaining the generated voltage (V), current (A) and frequency (Hz) waveforms to standard sinusoidal. The PQ problems are harmonic distortion, under voltages and over voltages, voltage unbalance, voltage flicker, voltage notching, voltage interruption, transient disturbances and frequency variations. These PQ problems are responsible for unwanted tripping of relays and circuit breakers, malfunction of sensitive electronic equipments, false reading of meters, heating of electric machines, noise in the machines, increase or decrease in the speed of motors. The causes of harmonic currents are non-linear loads, unbalanced loads, and reactive power (VAR) due to the heavy inductive loads. Voltage sag occurs due to switching of heavy loads and voltage swells occurs due to single line to ground faults in the power distribution system. The PQ problems mitigation techniques are active power-line conditioning like unified power quality conditioners (UPQCs), shunt filters, series filters, and hybrid active power filters (APFs), static synchronous compensators (STATCOMs) and dynamic voltage restorers (DVRs) [4].

The good idea is to use APFs for the termination of PQ issues. The shunt APFconfines the current related problems, which are current harmonics, reactive current, current unbalance and voltage related issues such as voltage harmonics, voltage sag, swell and voltage unbalance are compensates by the series APF. UPQC is the device which has both the above filters and provides the compensation to the three-phase power system by using dual compensation technique. The APF uses the pulse width modulation (PWM) to control the firing angle of the APFs. UPQC, compensates both the current and voltage related problem from the three-phase power system simultaneously [9]. The main purpose of this dual compensating technique with its principle advantages are as: i) eliminates harmonic current as well as voltage; ii) reactive power compensation to the load; iii) balances the load; iv) balance the voltage and current equally at 120 degree to each other; v) interruption free power (Watt); vi) eliminate the flicker from the supply. In this UPQC system, synchronous reference frame (SRF) dependent controllers $(dq0-\text{axes})$ are used to control input and output currents and voltage of the UPQC. Continuous control references into the SRF based controllers is allowed due to voltage and current references are alternating sinusoidal which decreases errors when proportional-integral (PI) controllers is implemented for this same reference frame. Thus, calculated bus phase angle θ obtain from phase locked loop (PLL) and θ is also use to generate the sinusoidal input current references.

To find the coordinates of the unit vector ($\sin\theta$ and $\cos\theta$) of the SRF-based controllers θ can be use for it. For UPQC system, a three-phase PLL (3pPLL) method is used with this 3pPLL, a self-tunning filter (STF) eliminates the harmonic currents and unbalances in the load. The location of STF is in between bus voltage and the 3pPLL. The 3pPLL first calculates angular frequency and this angular frequency adjust the STF cut off frequency. Thus, bus frequency can change the characteristic of STF. The UPQC can connect in three-phase three-wire (3P3W) or three-phase four-wire (3P4W) distribution system to compensate the losses of the line and enhance the PQ at utility as well as at the end user side. At plant site generally UPQC uses 3P3W and for single phase loads, the load needs fourth wire called neutral conductor. The control of the UPQC based 3P4W distribution system is calculated by the simulation and the p-q theory is used to obtain the references of the voltage and current as compensation. From experimental results we got static and dynamic performance of the UPQC [4].

II. BASIC CONCEPTS OF UPQC

Figure 1 shows a basic block diagram of UPQC system, consisting of three-phase series and shunt APF. Both the filter injects the voltage and current in the system. The series-active filter terminate the harmonics between a sub-transmission system and a distribution system and also diminishes the voltage flicker/imbalance as well as voltage regulation and harmonic compensation at the utility-consumer point of common coupling (PCC).

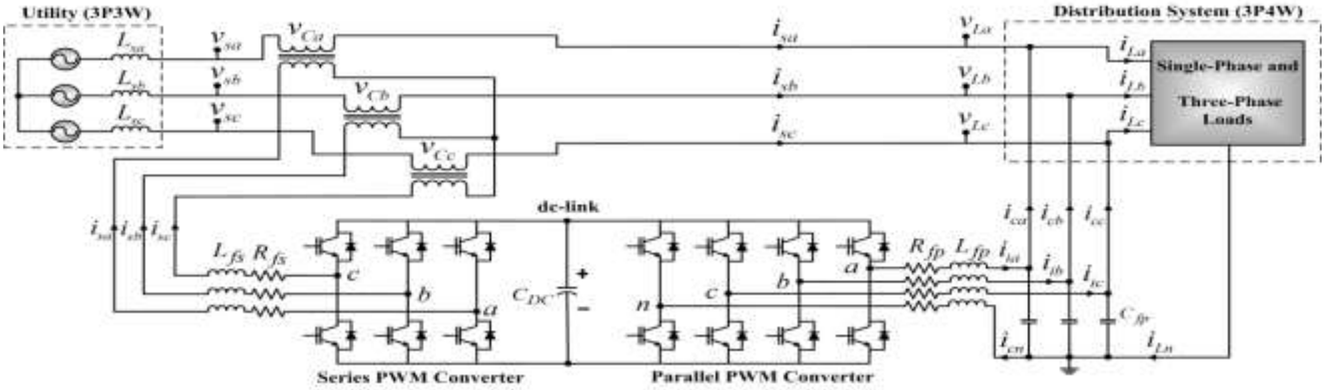

Figure 1. 3P4W distribution system based on UPQC connected to 3P3W power system.

The shunt active filter is used to absorb current harmonics, compensate reactive power and negative-sequence current, and regulate the dc-link voltage between both active filters. The integration of series APF and shunt APF is known as UPQC [12]. Injection of a series voltage in the system causes a phase angle difference between the source and load voltage without changing the resultant load voltage magnitude, a significant amount of reactive as well as active power would flow through series inverter. Proper control of the phase angle between the source and load voltage, the series APF can also help in compensating the load-reactive power demand [8].

III. UPQC CONTROL STRATEGY

In this paper the UPQC employed with dual compensation strategy is presented is shown in Fig. 1with both Three-Leg (3-Leg) and Four-Leg (4-Leg) PWM converters sharing the same DC-link. The UPQC is connected between a 3P3W power supply distribution system and a 3P4W plant site composed of several types of three-phase and single-phase loads. It is assumed that the single-phase loads use the neutral conductor to operate. In this case, a 3P4W distribution system is necessary, which is composed of three power conductors and a neutral conductor to feed the loads. Thus, it can be noted that, in the UPQC-based 3P4W distribution system shown in Fig. 1, the neutral current flows through the wire conductor connected to the fourth leg of the shunt 4-Leg PWM converter.

Control of Series APF

The control strategy of series APF uses the concept of unit vector template (UVT). The UVT is generated from the unbalance supply [11]. The process of extraction is shown in Fig. 2. The load terminal voltage should be (v_{La}, v_{Lb}, v_{Lc}) perfectly balance and sinusoidal with required amplitude. Series APF injects voltages opposite to the distortion/unbalance present in the source voltage and these voltages cancel each other resulting in a balanced and required magnitude voltage at the load side.

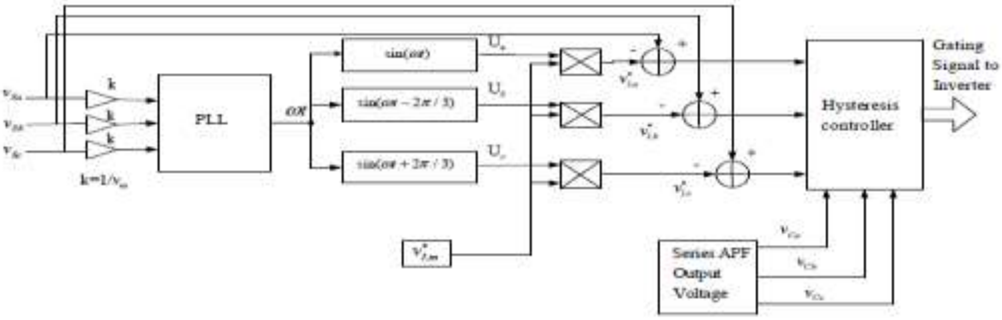

Figure 2. Control block diagram of series APF

The load reference voltage obtained by this control strategy is compared with the load voltage signals and the error is fed to a hysteresis controller which generates the required gating signal for the series inverter. The hysteresis band controller decides the pattern of switching in the inverters. This operation of the hysteresis controller is dependent on the error signal generated on comparing the load reference voltage and the instantaneous load voltage signals [5].

Control of Shunt APF

Sinusoidal reactive power theory, also known as p-q theory, is utilized to generate the reference signals for the shunt APF. Fig. 3 describes the control technique of the shunt APF. According to this theory the three-phase voltages and currents are measured instantaneously and by equation (1) and (2) are converted to $\alpha-\beta-0$ coordinates [5].

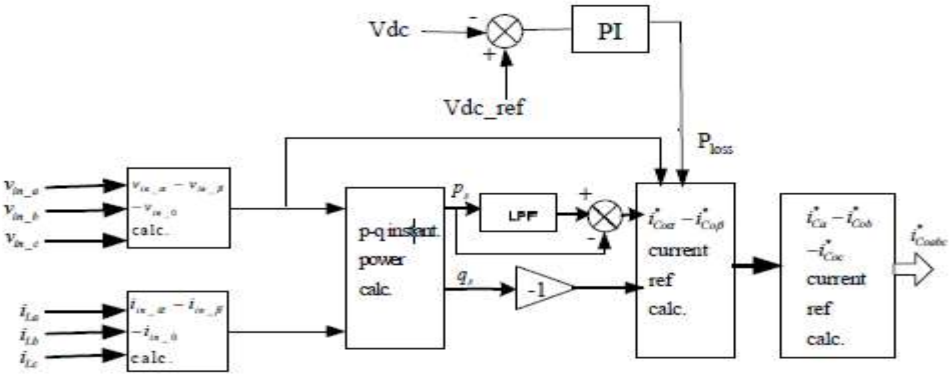

Figure 3. Control block diagram of shunt APF

$$\begin{bmatrix} v_0 \\ v_\alpha \\ v_\beta \end{bmatrix} = \sqrt{\frac{2}{3}} \begin{bmatrix} 1/\sqrt{2} & 1/\sqrt{2} & 1/\sqrt{2} \\ 1 & -1/2 & -1/2 \\ 0 & \sqrt{\frac{3}{2}} & -\sqrt{\frac{3}{2}} \end{bmatrix} \begin{bmatrix} v_{Sa} \\ v_{Sb} \\ v_{Sc} \end{bmatrix} \tag{1}$$

$$\begin{bmatrix} i_0 \\ i_\alpha \\ i_\beta \end{bmatrix} = \sqrt{\frac{2}{3}} \begin{bmatrix} 1/\sqrt{2} & 1/\sqrt{2} & 1/\sqrt{2} \\ 1 & -1/2 & -1/2 \\ 0 & \sqrt{\frac{3}{2}} & -\sqrt{\frac{3}{2}} \end{bmatrix} \begin{bmatrix} i_{Sa} \\ i_{Sb} \\ i_{Sc} \end{bmatrix} \tag{2}$$

Equation (3) shows real power (p), imaginary power (q) and the zero sequence components of the load. The real power and imaginary power are measured instantaneously. The source side real and imaginary power is calculated by using source currents and phase-neutral voltages as given in equation (3).

$$\begin{bmatrix} p \\ q \end{bmatrix} = \begin{bmatrix} v_\alpha & v_\beta \\ -v_\beta & v_\alpha \end{bmatrix} \begin{bmatrix} i_\alpha \\ i_\beta \end{bmatrix} \tag{3}$$

The real and imaginary power is,

$$p_0 = v_0 * i_0 \; ; \; p = \bar{p} + \tilde{p} \tag{4}$$

For reducing the neutral current, p_0 is calculated by using average and oscillating components.

$$\begin{bmatrix} i *_{S\alpha} \\ i *_{S\beta} \end{bmatrix} = \frac{1}{v^2{}_\alpha + v^2{}_\beta} \begin{bmatrix} v_\alpha & -v_\beta \\ v_\beta & v_\alpha \end{bmatrix} \begin{bmatrix} \bar{p} + p_0 + \bar{p}_{loss} \\ 0 \end{bmatrix} \tag{5}$$

$i *_{S\alpha,}$ $i *_{S\beta}$ and $i *_{S0}$ is the reference currents of shunt APF in $\alpha-\beta-0$ coordinates. These currents are transformed to three-phase system as shown in equation (6).

$$\begin{bmatrix} i *_{Sa} \\ i *_{Sb} \\ i *_{Sc} \end{bmatrix} = \sqrt{\frac{2}{3}} \begin{bmatrix} \frac{1}{\sqrt{2}} & 1 & 0 \\ \frac{1}{\sqrt{2}} & -\frac{1}{2} & \sqrt{\frac{3}{2}} \\ \frac{1}{\sqrt{2}} & -\frac{1}{2} & -\sqrt{\frac{3}{2}} \end{bmatrix} \begin{bmatrix} i *_{S0} \\ i *_{S\alpha} \\ i *_{S\beta} \end{bmatrix} \tag{6}$$

The load side neutral current, harmonics and reactive power are compensated by finding the reference current. After finding the reference current, signals are then compared with the three-phase source current, and the errors are processed by hysteresis band PWM controller to generate the required switching signals for the shunt APF switches [7].

IV. SIMULATION MODEL

The simulink diagram of UPQC is shown in Fig. 4. This model has been developed using MATLAB-Simulink. The objective of this model is to verify the harmonic, reactive power compensation and other PQ issues under different operating conditions. In Fig. 4, the three-phase and single phase non-linear load is connected across three-phase supply. The shunt APF is connected across the loads through shunt transformer, whereas the series APF is connected in a series with the line through series transformers. The series and shunt APF controls the reactive power in the system by maintaining the significant value of phase angle between the voltage and current.

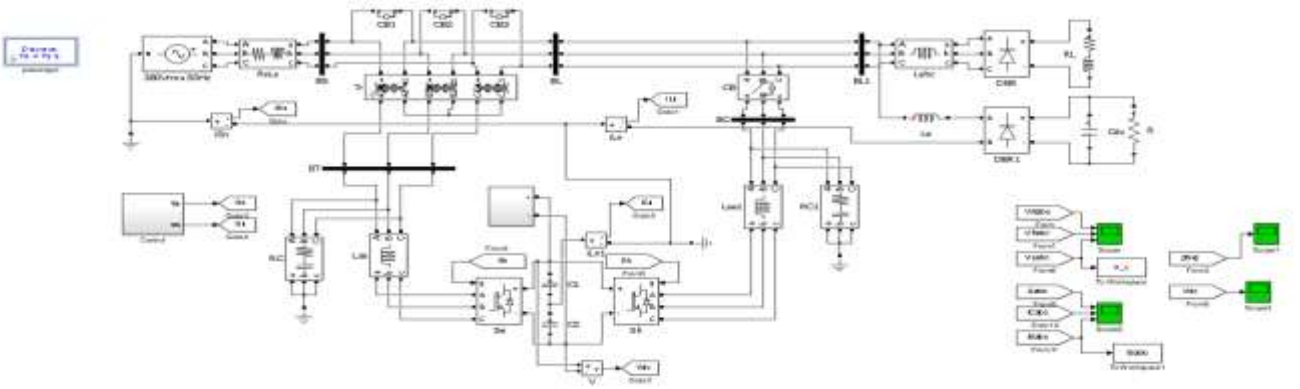

Figure 4. Simulation model of the UPQC system

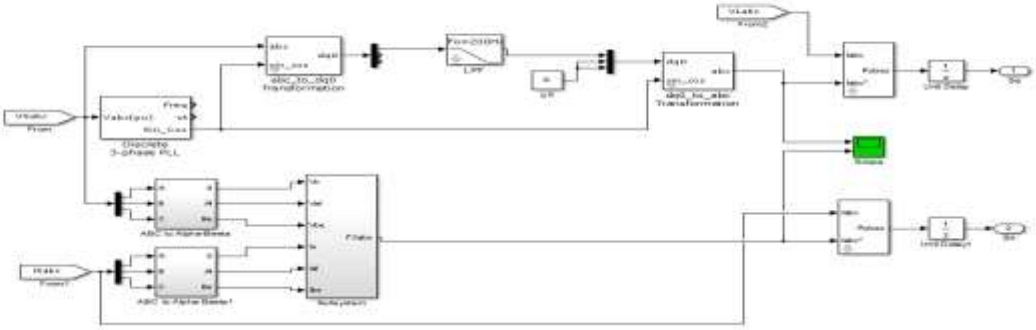

Figure 5. Simulation of combine series and shunt APF controller

Figure 5 shows the sub-system of the combine series and shunt APF controller; it has discrete three-phase PLL, LPF, dq0 to abc converter, abc to αβ0 converter etc.

V. RESULTS

In Fig. 6, the reference voltage and current of series and shunt APF has more distortion and as soon as the UPQC connected in the system the voltage and current distortion have been significantly reduced.

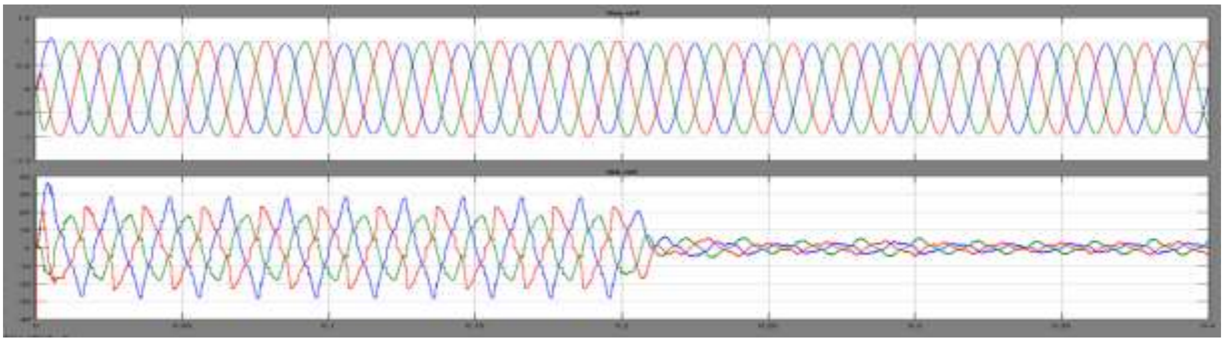

Figure 6. Waveforms of reference voltage and current of series and shunt APF.

Figure 7 shows the three-phase source voltage, terminal voltage and load voltage waveforms ($VS_{abc,}VT_{abc}$ and VL_{abc}), before 0.2 second the UPQC is not connected in the system, after 0.2 second the UPQC is connected in the system. After 0.2 seconds the source voltage, terminal voltage and the load voltage have minimum distortion. The results of the UPQC system are obtained under steady-state and dynamic load operation.

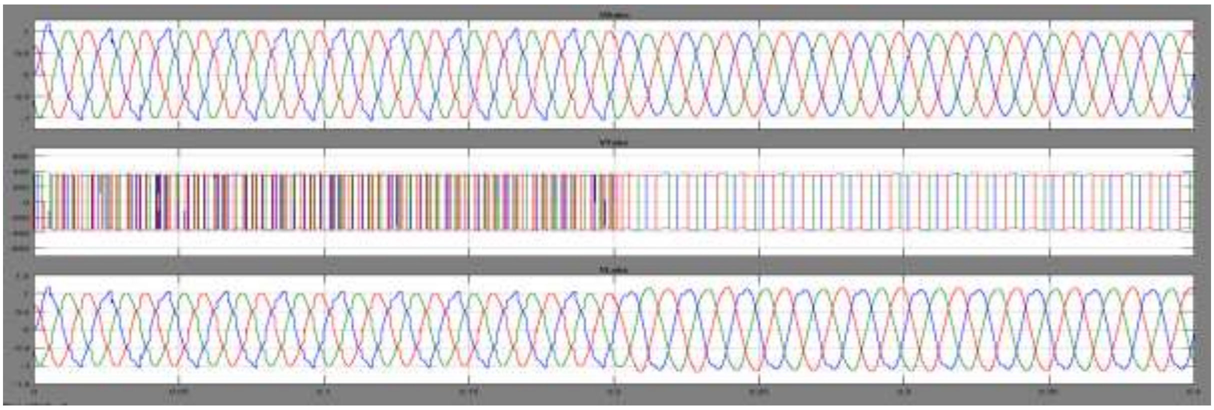

Figure 7. Waveforms of the three-phase source voltage, terminal voltage and load voltage ($VS_{abc,}VT_{abc}$ and VL_{abc})

The fast fourier transform (FFT) analysis of the source current and the load voltage is shown below. In Fig. 8(a), the percentage total harmonic distortion (THD) of source current IS_{abc} when UPQC is not connected in the system is as shown. The %THD is 27.27% which is high.

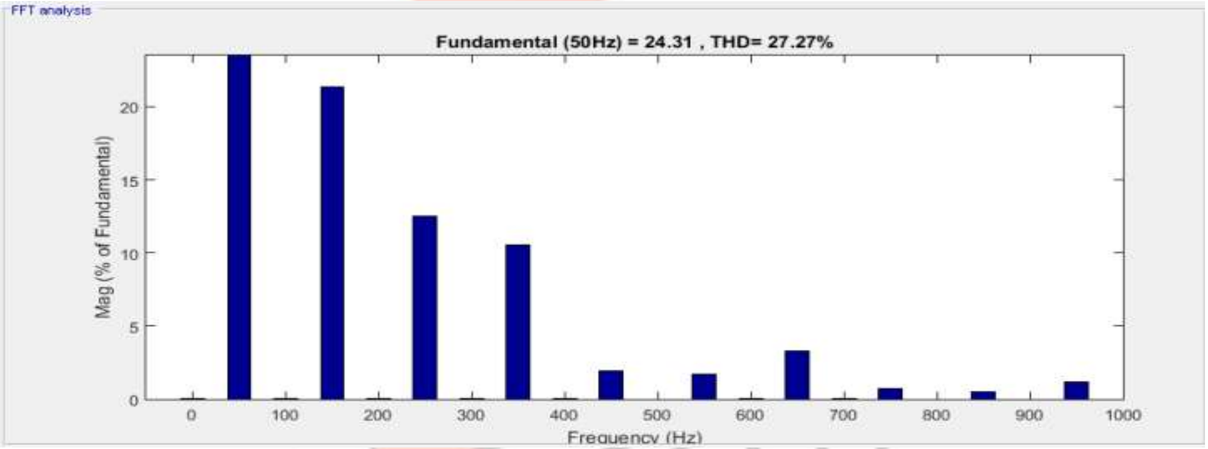

Figure 8(a). FFT analysis of the source current IS_{abc}

In Fig. 8(b), the %THD of source current IS_{abc} when UPQC has been connected in the system is as shown. The %THD is 4.99%

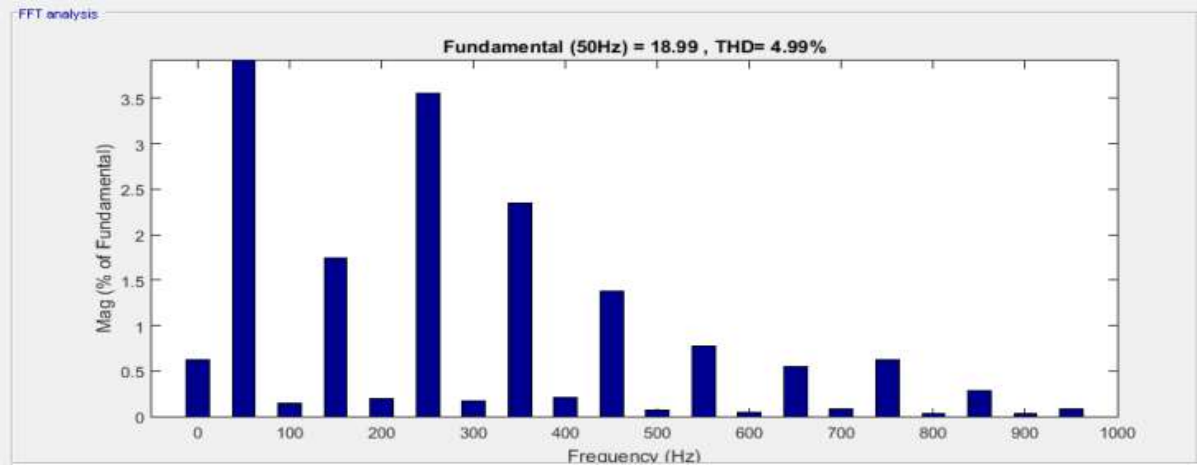

Figure 8(b). FFT analysis of the source current IS_{abc} after the UPQC connected in the system

Figure 9(a) shows the %THD of load voltage V_L when UPQC is not connected in the system is as shown. The %THD is 10.36% which is high and produces the PQ problems at end user as well as at the utility side also.

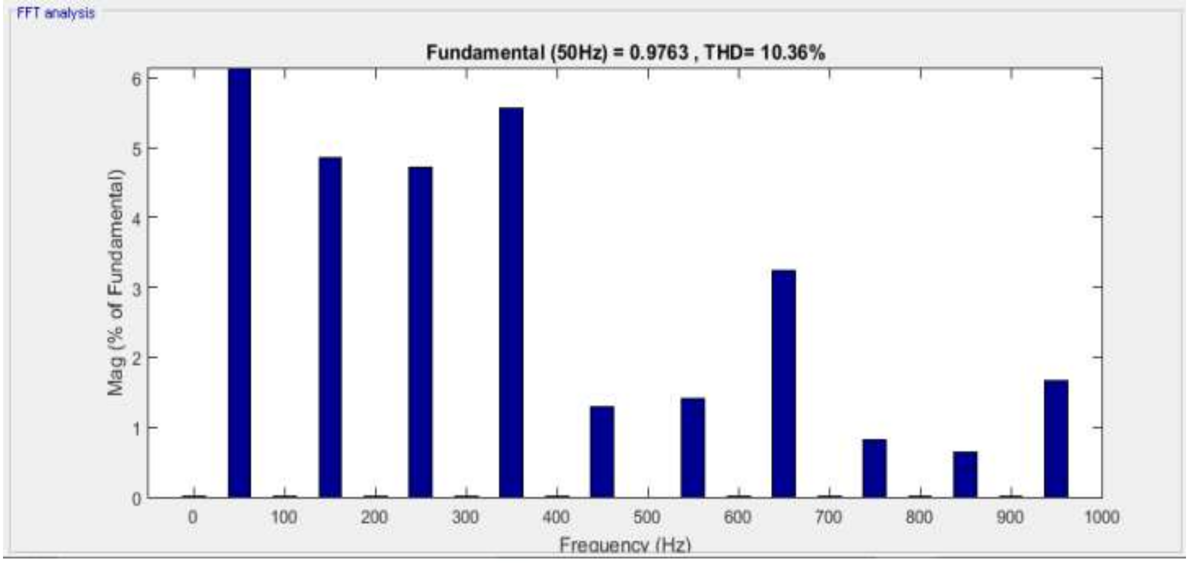

Figure 9(a). FFT analysis of load voltage V_L before the UPQC operation

Figure 9(b) shows the %THD of load voltage V_L when UPQC has been connected in the system is as shown. The %THD is 7.45%.

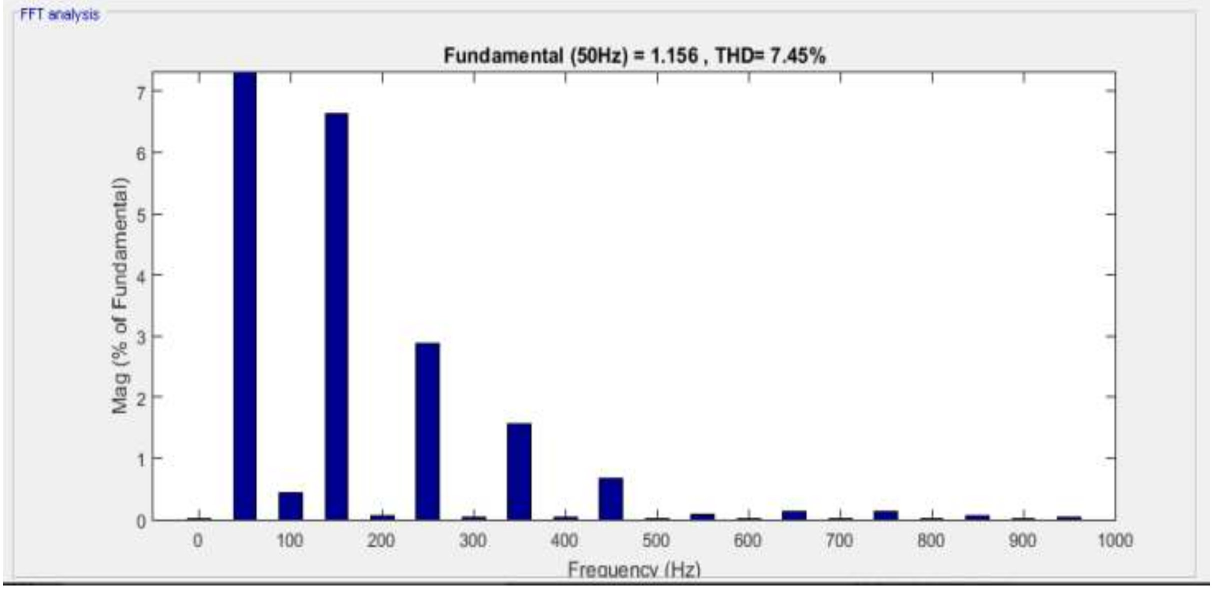

Figure 9(b). FFT analysis of the load voltage after the UPQC operation

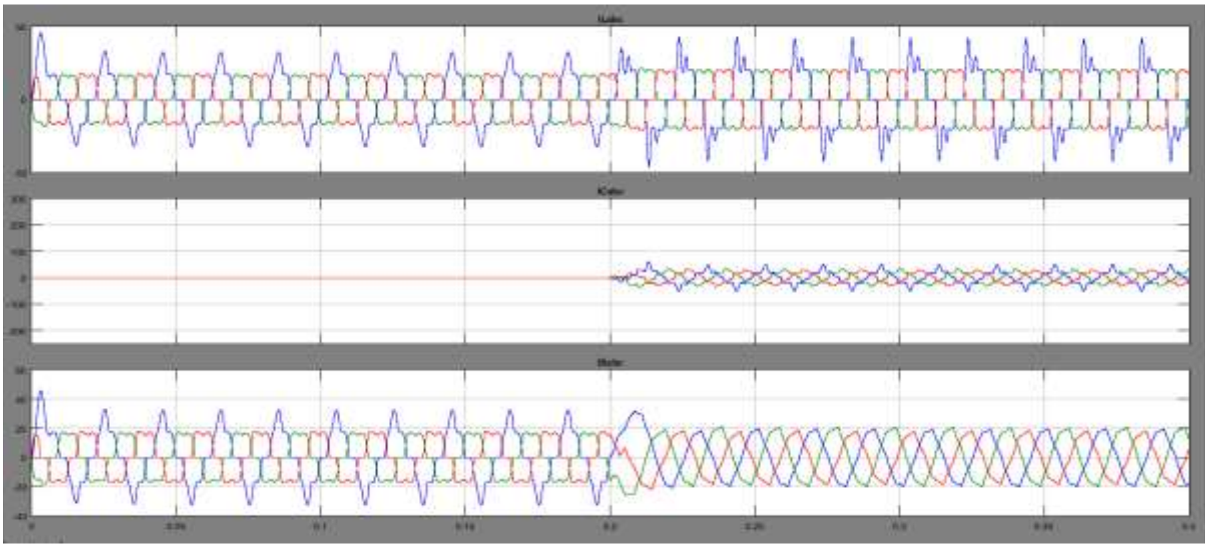

Figure 10. Waveforms of the load current, filter current and source current of the system (IL_{abc}, IC_{abc} and IS_{abc}) with and without the operation of UPQC

In Fig. 11, the neutral current becomes zero is as shown. When neutral current becomes zero then all the three voltages and currents are in phase and phase angle ∅ is near to zero.

Figure 11. Waveform of the neutral current

VI. CONCLUSION

This paper presents a dual control technique of UPQC to reduce the PQ problems. The UPQC is connected to the three-phase bus to compensate reactive power and to reduce the voltage and current harmonics in the polluted loads. The p-q theory is utilized to generate the reference signals for the shunt APF and the series APF used the concept of unit vector template (UVT). From the above simulation results, the performance analysis on the basis of %THD and it is observed that it reduces as per IEEE Standard.

VII. ACKNOWLEDGMENT

This study is supported by the Department of Electrical Engineering, S. D. College of Engineering, Selukate, Wardha (INDIA). This work is carried out as a part of Master of Technology project.

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